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A COMPARISON OF TECHNIQUES OF DETERMINING
VELOCITY IN THE TRACK SPRINT START

by

LOUIS L. LANIER



A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF ARTS

FACULTY OF PHYSICAL EDUCATION

EDMONTON, ALBERTA

MAY, 1968

UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read,
and recommend to the Faculty of Graduate Studies for
acceptance, a thesis entitled "A Comparison of Techniques
of Determining Velocity in the Track Sprint Start"
submitted by Louis L. Lanier in partial fulfillment
of the requirements for the degree of Master of Arts.

ABSTRACT

The purpose of this study was to compare the use of force-blocks and cinematography in the measurement of horizontal velocity obtained in the track sprint start. In addition, an attempt was made to evaluate the information produced by the force-blocks.

An experienced fifty-yard sprinter of the University of Alberta track team was the only subject used. The start blocks were set to the subject's preferred foot spacing (twelve inches toe to toe). Eighteen legal and technically acceptable starts were analysed.

A Brush recorder provided a graphic record of the maximum force exerted by the subject against the force-blocks, the reaction time of the subject, and the length of time that each foot remained in contact with the blocks. By measuring the area under the force-time graph, impulse and velocity produced by the start were calculated.

Each start was recorded on film by cinematography. The velocity of the subject on leaving the blocks was calculated after determining the horizontal distance the subject's centre of gravity travelled from the time his front foot left the force-blocks to the moment prior to his back foot touching the floor, and the elapsed time recorded on the film. The first method of measuring this horizontal movement was by projecting vertically onto a platform, two selected images of the subject. The subject was placed on the platform in these positions and the horizontal change in the distribution of the subject's weight on the platform was measured. In the second method, tracings of these images were placed on the platform to provide the guide in the positioning of the subject. The

procedure used in the vertical projection technique was repeated.

There was no significant difference in the mean velocities obtained from the force-graphs and the vertical projection method. However, the mean velocity obtained by the tracing method was significantly greater than the other two means ($p = .05$).

Test-retest reliability coefficients of 0.73 and 0.36 were obtained for the force-graph and the tracing methods respectively. There was a high correlation coefficient of 0.83 between the impulse of the front foot and the velocity obtained from the force-graphs, and a high negative correlation coefficient of -0.81 between the impulse of the front foot and that of the back foot.

Based on the results obtained, the following conclusions appeared to be justified:

1. There was not a significant difference between the mean velocity determined from the force-blocks data and the mean velocity obtained from the vertical projection method.
2. The tracing method yielded a significantly greater velocity ($p=.05$) than did the other two techniques used in the study.
3. The force-blocks provided a quick method of calculating velocity compared to cinematographical analysis.
4. The true mean velocity of the starts studied was not less than $10.3(^{+}0.6)$ feet per second.
5. The front foot contributed twice the impulse to final block velocity as did the back foot.

ACKNOWLEDGEMENT

The author is most appreciative of the assistance, constructive criticisms and encouragement given by members of his committee, Mr. R.G. Glassford (chairman), Dr. S. Mendryk and Dr. D.B. Scott. Also to Mr. G.M. Elliott who served as an ex officio member of the committee and assisted greatly in defining the problem. Their guidance throughout the study made its completion possible.

A special acknowledgement is extended to Dr. M.L. Howell, under whose supervision the force-blocks used in this study were designed and fabricated at the University of Alberta. Without this vital and unique piece of apparatus, this study would not have been possible.

The author is grateful to Mr. Larry Dufresne who served unselfishly as the only subject.

To Elizabeth, my wife, whose understanding, assistance and constant encouragement made it possible for the author to complete this task, my love and gratitude.

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CHAPTER I

STATEMENT OF THE PROBLEM

I. INTRODUCTION

It is generally agreed that the start plays an important role in track and field sprinting. The ancient Greeks demonstrated the importance they placed on the sprint start by cutting holes into slabs of stone for the runners to place their feet at the beginning of the race. In modern athletics starting blocks were introduced by Bresnahan (3) in 1927 to provide a firmer base of support for runners to thrust against, than that provided by holes dug into the track.

Since the acceptance of starting blocks a number of studies (12,24,28,41,42,45) have been conducted for the purpose of determining what block spacing contributed most to a fast sprint. In these studies three main classifications of starting positions, based on the block spacing, were compared; the bunch, medium and elongated starting positions. In an attempt to answer this question, Kistler (28) in 1934 measured the force exerted against the starting blocks by his subjects, concluded that the most forceful start produced the fastest sprint. Dickinson (12) reasoned that the quickest start would result in the best sprint time. The results of these two investigators appeared to be in conflict. However, in 1952 Henry (24) measured the velocity of and the force exerted by sprinters and timed them over distances up to fifty yards. His results indicated that a sprinter using a position that enabled him to achieve

a more forceful thrust from the blocks by spending more time on the blocks. More recent studies by Sigerseth and Grinaker, (41) and Stock (45) support Hentry's findings whereas the results of Sills and Carter (42) appear to disagree. These studies measured velocity for distances up to fifty yards.

Since Muybridge's (33) use of photography to examine the gaits of animals in 1882, the camera has been used extensively to study human movement. In most cases the purpose has been to describe complex movements with greater accuracy. However, in 1930 Fenn (16,17) conducted a major cinematographical study of a human subject running, in which he measured the work done, the velocity and the path of the center of gravity. Groves (22), in 1950, placed divers on a platform, supported by four scales, in thirteen diving positions. The coordinates of the subject's center of gravity was calculated using the readings from the scales. Then in analysing a dive, which was filmed, these results were used in estimating the path of the subject's center of gravity. McIntosh (30) modified this technique by projecting a life size image on to a platform placed in a vertical position. The image was traced on the platform and the platform was then placed on the scales. The location of the center of gravity for that image was determined by having the subject assume that position on the platform following which the necessary calculations from the scale readings were made.

Only one study was found in the literature that compared measures obtained mechanically with those determined by cinematographical analysis. Russell (36) measured the velocity achieved in a swim start using a force-platform. These values were compared to those determined by analysing

motion pictures of the same start.

II. THE PROBLEM

The purpose of this study was to compare the use of force-blocks and cinematography in the measurement of horizontal velocity obtained in the track sprint start.

Secondary Problems. The secondary problems of this study were:

1. To determine the maximum force exerted by each foot on the force-blocks.
2. To determine the relative contribution to velocity of the impulse exerted by each foot.
3. To measure the total time force was exerted on the force-blocks.
4. To estimate the error involved in measuring velocity by these methods.

Hypothesis. There should be no difference in the results obtained using force-blocks and cinematographical analysis in the measurement of the horizontal velocity attained in the track sprint start.

Importance of the study. This was the first major study to be carried out on force-blocks, which used transducers to ascertain velocity. This study provided an evaluation of the information obtained from this equipment which will enable others to carry on further research in this area using these force-blocks.

Other than the study by Russell (36) few, if any, studies have compared mechanical and cinematographical methods of measuring velocity.

Limitations. The following limitations applied to this study.

1. Only one subject was used in the study, and therefore no references to any population can be made.
2. No attempt was made to determine the lateral or vertical movement of the center of gravity or their casual forces.

III. DEFINITION OF TERMS

Force blocks. The force blocks are sprint start-blocks designed to measure the horizontal component of force in the line of start.

Toe-boards. The toe-boards are those surfaces of the force-blocks against which the subject places his feet in the sprint start.

Sprint start. In this study a sprint start refers to a start in a track and field activity. The start begins with the firing of the starting gun and ends the moment the subject's back foot touches the floor in front of the starting line.

Back-foot. The subject's foot that is farthest from the starting line at the beginning of the sprint start shall be designated as the back-foot.

Horizontal force. The horizontal force is that component of the total force that is exerted on the blocks in a horizontal direction in a sagittal plane.

Impulse. The impulse is a vector quantity determined by multiplying the time average of the force by the time interval during which the force acts.

Velocity. The velocity is a vector having the same direction as the displacement which took place during the time interval in which

the velocity was measured.

Center of gravity. The center of gravity of a body is that point which the sum of the moments of gravitational forces is zero.

Cinematography. Cinematography is defined for the purposes of this study as the taking of motion pictures under carefully controlled conditions in order that precise measurements of time and motion may be made.

Cinematographical analysis. Cinematographical analysis consists of the techniques of determining measurements from motion pictures.

CHAPTER II

REVIEW OF LITERATURE

I. THE TRACK SPRINT START

A few years after the introduction of starting blocks in 1927, physical educators began to study the track sprint start scientifically. One of the first studies reported, was by Hayden and Walker (23) in 1933, who investigated the respective starting times of sprinters using holes in the track and starting blocks. Their results, based on 2300 trials, indicated that a sprinter got off to a faster start using the blocks. Following this a number of studies were carried out, whose prime purpose was to determine which starting position, classified according to the space between the blocks, contributed most to a fast sprint.

In 1934, Kistler (28) used counter-sunk spring scales attached to the starting blocks to measure the force exerted by the sprinter in four different positions. He found that the combined force exerted by both feet to be; 346 pounds using the buch start (11 inch spacing), 303 pounds using the medium start (16 inch spacing), 386 pounds using the medium start (21 inch spacing) and 404 pounds for the elongated start (26 inch spacing). The resultant implication was that in general the greater the distance (within limits) between the blocks the more powerful the start. In the same year Dickinson (12), who used an automatic chronoscope activated by the starting gun, found that the average time required to reach a line 2.5 yards in front of the starting line

was: 0.086 seconds from the bunch position and 0.887 seconds from the elongated position. The starts from the medium positions produced intermediate times. The time necessary to clear the blocks was found to be shorter the closer the blocks were spaced.

Henry (24) conducted a more elaborate study in 1952 in an attempt to resolve the apparent contradiction in Kistler's and Dickinson's findings. He designed a set of starting blocks in such a way that the force exerted against them was recorded on graph paper. From the resulting graphs he was able to calculate the velocity of the sprinter on leaving the blocks. On the same graph paper was recorded the starting signal and the instant the runner passed a series of timing stations placed at five yards, ten yards and fifty yards from the starting line. The results obtained indicated that the bunch start enabled the sprinter to leave the blocks in the shortest time but with the least velocity which resulted in a significantly slower time for fifty yards. The elongated start produced the most powerful start and the greatest velocity on leaving the blocks but this advantage was lost within the first ten yards, being significantly slower than sprints from sixteen inch spacing. Sprints from the blocks spaced at sixteen inches were significantly better than those from the bunch and elongated positions but not those from the twenty-one inch spacing. Henry (24:317) defined the ideal start as ". . . early development and maintenance of full maximal thrust with each leg until the respective blocks are cleared as a necessary result of forward motion."

The study conducted by Sills and Carter (42) used the bunch, the medium and the subjects' preferred position. The subjects sprinted

thirty yards faster, using the bunch start than they did from a medium block spacing. These results appear to conflict with those of Henry's.

Sigerseth and Grinaker (41) determined the time required to sprint distances up to fifty yards measured at ten yard intervals, using the three block spacings described by Brisenahan et al. (3). The sprints from the medium start were faster at all distances but there was only a significant difference between the medium and the elongated starting position at fifty yards. The time required to sprint thirty yards using a bunch spacing was significantly shorter than that from the elongated position.

In the same year, 1962, Stock (45) used the three general classifications of starts with the addition of a medium start in which the hips were raised much higher than usual. The time required to sprint twenty and fifty yards was obtained. The bunch and medium high hip positions produced significantly faster times at twenty yards whereas the medium high hip start resulted in significantly faster times at fifty yards.

II. CINEMATOGRAPHY

The motion picture has become an increasingly useful instrument in analysing human motion. As early as 1892 Muybridge (33) used it to study in great detail the manner in which animals moved. In 1933 Fenn (16,17) conducted one of the first major studies of a man running. The subject ran behind a white wooden lattice framework composed of one meter squares. To determine the film speed balls were dropped in front of a vertical scale, and appeared at the side of the film. Fenn measured

the subject's velocity, the path of his center of gravity and the work done by the subject. In determining the center of gravity he used the segmental method based on data developed by Braune and Fischer (2). Throughout his study he mentioned the problem of measurement error, for example, "The determination of waist velocities are, however, themselves subject to considerable error. . ." (17:447). Wherever possible he estimated ". . . the error in measuring their horizontal velocity from their positions in relation to the lattice was 1.7 per cent." (16:588).

Cureton (9) in describing the uses of cinematography in research saw its value in measuring the velocity of implements and in calculating the degrees through which the human body and its limbs move in performing complex skills. Quandt (34) reported a study in which he analysed the pitched ball in baseball in order to determine the ball's velocity and to compare finger joint movements of different pitches.

Three studies in recent years by Beck (1), Deshon and Nelson (11) and Dittmer (13) have examined the act of running. Both Beck and Dittmer measured linear velocity of the body and angular velocity of the extremities. They also plotted the path taken by the center of gravity. The third study was concerned with the angle of leg movement and the velocity of the stride in running.

Grieve and Gear (21) examined the walking stride of children under eleven compared to adults, over a wide range of speed. Chronocycle-photography, a device for producing multiple images on a single photograph with known time intervals between exposures, was used to measure the length of stride (± 1 per cent) and step frequency ($\pm 2\frac{1}{2}$ per cent) of

the children. For older subjects a standard motion picture film taken at thirty-two frames per second was used. Measurements taken from the film were accurate within $\pm 1\frac{1}{2}$ per cent. The speed of the leg swing was also measured.

In 1950 Groves (22) studied the mechanics of diving, in which acceleration and angular velocity were measured from motion pictures. In order to achieve a higher degree of validity he sought a more accurate means than the segmental method of determining the center of gravity, which will be discussed later.

In searching the literature the only study found that attempted to calculate the velocity of a human subject by both mechanical and cinematographical techniques, was that of Russell's (36). He measured the velocity which a swimmer obtained in a swim start by placing the starting block on a force platform which recorded vertical, horizontal and lateral forces on graph paper. In calculating the velocity from an analysis of the film he determined the subject's center of gravity using data developed by Dempster (10). The correlation coefficient calculated for the cumulative impulse for both methods was 0.537. Russell was of the opinion that errors in determining the center of gravity and in measuring film speed were the main contributing factors to this low correlation.

III. CENTER OF GRAVITY

Steindler (44:34) stated that, "For centuries the determination of the weight center of the body has held the interest of mathematicians and physiologists." As early as 1679 Borelli (cited in 44) determined

the center of gravity in both the sagittal and transverse planes, by balancing the body on a flat board. The work of Braune and Fischer in 1889 has become a classic work. They suspended frozen cadavers in three different axes, perpendicular to each other. The center of gravity was located at the point where the three lines of gravity intersected. This procedure was repeated to determine the center of gravity of various segments of the body.

In 1909 Lovett and Reynolds (29) developed a method of locating the line of gravity in the sagittal plane, based on Newton's law of action and reaction. A board was supported by two prismatic ledges one of which rested on a scale. The distance (D) between the ledges as well as the total weight (W) of the individual was first determined. The subject was then placed on the board facing the scale and the anterior weight (A) was read on the scale. The distance (Y) that the line of gravity was from the ledge on the floor was calculated using the formula: $Y = AD/W$.

In conducting research into the space requirements of a pilot, Dempster (10) revised Braune and Fischer's data, using seven cadavers of medium build. He developed tables which showed surface landmarks associated with joint centers and percentage distance the center of gravity points were from joint axes.

One of the problems in studying the body in motion has been, as previously mentioned, the determination of the center of gravity of the body in various positions. Most of the studies reviewed, (1,13,16,21,36), that have been concerned with this problem, have relied on the segmental method of determining the center of gravity. This technique is not

only painstaking but, because of the vast number of measurements that have to be made, is subject to considerable error (16,17,22,36,38). Of significance also is the fact that available tables do not apply to all body types.

In his effort to develop a more convenient and more accurate method of determining the center of gravity, Groves (22) modified the method of Lovett and Reynolds. A platform, divided into four quadrants by two intersecting white lines, was supported at each corner by a scale. The subject was placed on the platform in one of thirteen diving attitudes and the scale readings recorded. Using the scale readings calculations, based on the principle of movements, were made to determine the location of the subject's center of gravity in each appropriate position. This point was marked in a contrasting color and a photograph taken from a position thirty feet directly above the platform. These photographs were then used as a guide to estimate, from motion pictures taken of a dive, the path taken by a diver's center of gravity.

A few years later McIntosh (30) used a similar technique. With the platform, used to determine the center of gravity, held in a vertical position, a life size image of the subject was projected on it. This image was then outlined with chalk. After the platform was placed on the scales the subject was placed on it in the same attitude as the tracing. The method described by Groves of calculating the co-ordinates of the center of gravity was used. By repeating this procedure for each frame of a motion picture taken of a performed skill, the path of the center of gravity during the movement was determined.

CHAPTER III

METHODS AND PROCEDURES

The experimental study was conducted in the gymnasium of the University of Alberta. The environmental variables of weather and light were more easily controlled in this indoor setting.

I. APPARATUS

Force-blocks. The force-blocks (Figure 1) were designed and fabricated at the University of Alberta. Each toe-board was covered with corrugated rubber and mounted on a channel-iron, which was carried by a front shackle, mounted on a half inch torsion bar, and a pair of shorter rear shackles, mounted on a round shaft. Since the front and rear shackles were different lengths, only horizontal movement of the channel iron was permitted.

The horizontal force exerted against the toe-board was measured by a Sanborn 7DCDT displacement transducer (Figure 2), which generated a potential difference proportional to the force exerted against the toe-board. This potential difference passed through a differential transformer and activated the Brush recorder.

A metal pointer was mounted on the side of a force-block by a lever arrangement in such a manner as to amplify any horizontal movement of the toe-board twenty times.

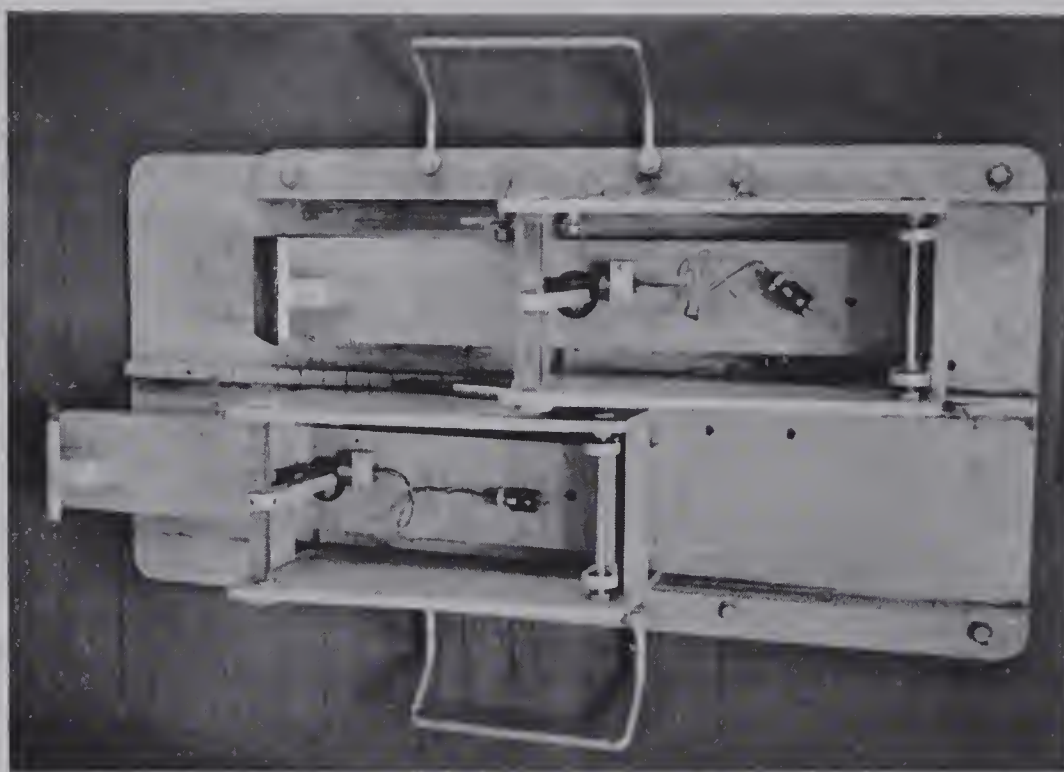


FIGURE 1

TOPVIEW OF THE FORCE-BLOCKS DESIGNED BY HOWELL

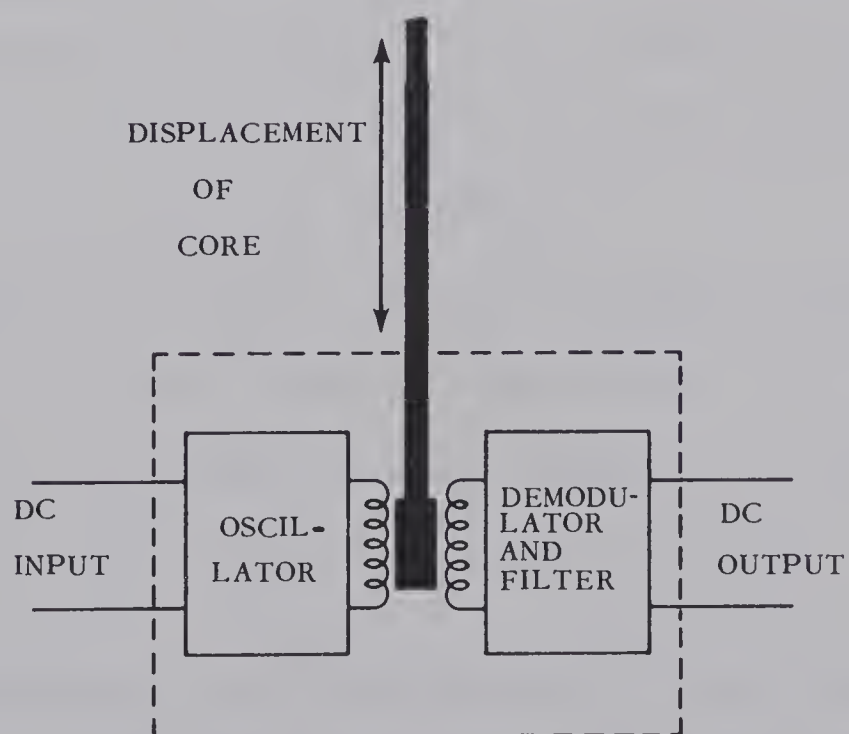


FIGURE 2

FUNCTIONAL DIAGRAM OF THE SANBORN DISPLACEMENT TRANSDUCER

Brush recorder. A Brush Recorder Mark 11 recorded the electrical impulses from the transducer by means of pen displacement on graph paper. The following settings were used; the volt/short line at .05, the sensitivity at x1, and the paper speed at 125 millimeters per second.

Planimeter. A Coradi Compensating Planimeter was used to measure the area of the force-time graph obtained from the Brush recorder.

Starting gun. The trigger of the starting gun was a micro-switch, which was electrically connected to the Brush recorder and to a photographic flash attachment. When the trigger caused the blank cartridge to fire, this was simultaneously recorded on the graph paper by a deflection of the pen, and on the film by the flash of the bulb.

Timing devices. A chronoscope, which had a one-second sweep hand, recorded time in hundredths of a second. It was filmed throughout the entire experiment in order to determine the film speed of the camera and to determine the speed and velocity of the subject.

To time the subject over a distance of twenty yards, a mercury switch was connected in circuit with the chronoscope. A cord from the switch was attached to the subject in such a manner as to trip open the switch the moment the subject reached the twenty yard line.

Point of reference. A "Dexion" angle iron beam (Figure 8) six feet by two and one quarter inches was mounted above the center line of the force-blocks in a horizontal position. It was fifty-one inches above the floor and extended three and one half feet in front of the starting line. By marking the beam at six inch intervals with one inch white tape

it served as a point of reference on the film, and from it horizontal measurements were made.

Camera. A spring driven Bell and Howell model 70SR camera was used to record each start on film. The lens had a focal length of one inch and the shutter opening was 204 degrees with a shutter speed of .004 seconds. A diaphragm opening of f/2.5 was used and the film speed was set at 128 frames per second. By adding a "split-lens" the focal length of one half of the camera lens was shortened so that the chronoscope could be placed three feet in front of the camera during the filming.. The subject was filmed through the unchanged half of the lens.

Sixteen millimeter Tri X Reversal film was used, which had an ASA rating of two hundred.

Projectors. A Bell and Howell, model No. 8399 AV, projector, equipped with a five-eighths inch lens, was used. It was mounted on a scaffold nine feet four inches directly above the center of gravity platform, which was positioned between the scaffold legs. This positioning made it possible to project a life size image of the subject on the platform.

A Specto, type No. FS, projector equipped with a two inch lens was used to project a life size image horizontally on a wall. It was designed to project sixteen frames per second, one frame per second or to stop the action on any desired frame.

Center of gravity platform. The center of gravity platform

(Figure 3 and 4) consisted of a plywood board four feet wide and seven feet long. At one end of the board, adjustable metal legs six inches long were placed at each corner; at the other end of the board a metal leg of the same length was placed midway between the corners. Each leg rested on a scale calibrated in quarter pound intervals.

At the top of the platform (Figure 10) an actual size drawing of the "Dexion" beam was made showing the white tape markers. When the film was projected on the platform the image of the beam was matched with the drawing to insure that the projected image was life size.

II. PROCEDURES

Calibration of the apparatus. The apparatus was calibrated prior to conducting the study. In each case the mean, the standard deviation and the relative error of the information obtained from each item of the apparatus was determined. (Appendix B).

Each force-block was attached to the Brush recorder and then clamped in a vertical position, with the toe-board removed. The following weights of a known mass of: 50.0, 99.5, 149.0, 200.0 and 249.25 (± 0.06) pounds were placed on the end of the channel iron, and thirty repetitions of the pen deflection were recorded in each case on the graph paper. From measurements taken of the graphs it was calculated that the front force-block required a force of 6.72 (± 0.152) pounds for each millimeter of pen deflection and the back force-block required a force of 6.02 (± 0.084) pounds per millimeter.



FIGURE 3

TOPVIEW OF THE SUBJECT ON THE CENTER OF GRAVITY PLATFORM



FIGURE 4

SIDEVIEW OF THE SUBJECT ON THE CENTER OF GRAVITY PLATFORM

A digital counter (accurate to the nearest 0.0001 second) was connected to the event marker switch of the Brush recorder. With the recorder in operation, and the paper speed set at 125 millimeters per second, the marker switch was closed and this caused the event marker pen to deflect and the digital counter to start. The switch was held closed for one half to four seconds. This was repeated fifty times and the time recorded on the respective graph. The resultant mean speed of the graph paper was 124.9 (± 0.68) millimeters per second.

The planimeter was adjusted to produce a reading of forty square inches when measuring the area of the circle described by the calibrated ruler (Coradi instruction manual). A mean of 39.99 (± 0.014) square inches was obtained from ten repetitions. In making ten measurements of two selected graphs, the graph produced from the force exerted by the front foot gave a mean of 1.073 (± 0.015) square inches and that from the back foot a mean of 0.588 (± 0.014) square inches.

The chronoscope used in the study had a synchronous motor so that its speed was directly proportional to the frequency of the current. In the city of Edmonton the maximum variation in frequency is 0.001 cycles per minute.

The film speed of the camera was not constant having a range from 117 frames per second to 140 frames per second. However the film speed was calculated for each start by counting the number of frames (which included the start) for a period of 0.500 (± 0.002) seconds.

The mean time between Frame I and Frame II, which was used in calculating velocity by the cinematographical method, was 0.054 (± 0.002)

seconds. This deviation from the mean was the estimated error in the administrator's ability to read the time from the image of the chronoscope on the projected film.

The scales used in the study were of the balance type, which permitted the estimation of weight to the nearest quarter (± 0.13) pound.

In making measurements on the projected image for the purpose of determining the horizontal movement of the subject's center of gravity, an accuracy of ± 0.5 inches was estimated.

Subject. The subject was a member of the University of Alberta track team, and was considered to be one of the best sprinters on the team over a distance of fifty yards. He weighted 174 pounds and was five feet ten inches tall, being a mesomorph somatotype. The subject had participated in the pilot study a month before and therefore was familiar with the apparatus. The force-blocks were adjusted to his preferred spacing; the front and rear toe-boards being twenty-two inches and thirty-four inches respectively from the starting line. The subject was instructed to warm up for fifteen minutes and then do three practice starts. He was told that he would be expected to perform twenty legal and technically satisfactory starts, exerting his maximum effort each time. There was a rest period of approximately three minutes between each start. The subject was given the command "on your mark", as soon as he was settled in this position the command "set" was given, and the gun was fired as soon as the subject was steady. On each occasion the timing device was attached to the subject, and he was timed for a distance of twenty yards. If in the opinion of the starter a false start had occurred it was not recorded and he called the subject back for another try, allowing him

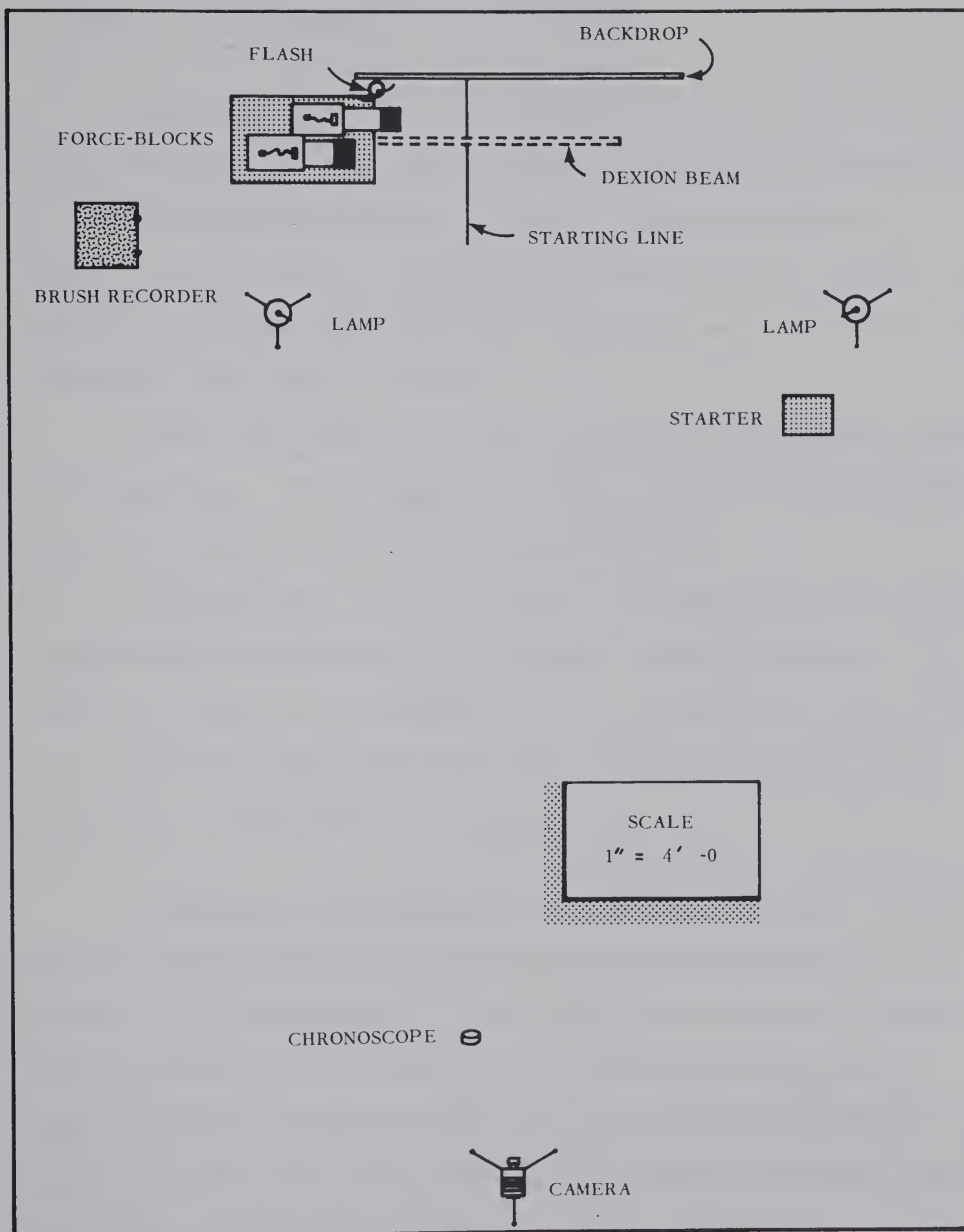


FIGURE 5

SCHEMATIC DIAGRAM OF THE APPARATUS IN POSITION FOR THE STUDY

to rest for three minutes.

Cinematography. The camera (Figure 5) was located so that its lens was twenty-four feet from the line of sprinting and perpendicular to it. The distance was measured from the front of the lens to a point one foot in front of the starting line and in line with the center of the force-blocks. The height above the floor was thirty-three inches measured to the center of the lens.

Three flood lights were used to supplement the regular lighting in the gymnasium. A white sheet of plywood was placed on the opposite side of the subject to produce greater definition.

The camera was started at least two seconds before the starting gun was fired to insure that the film speed reached a constant rate before the subject left "his mark". It was stopped soon after his back foot touched the floor. The chronoscope was started before each trial by closing the switch of the timing device.

Collection of data from the force-blocks. The graph obtained from the Brush recorder contained the following information; (1) the firing of the starting gun, (2) the elapsed time between the firing of the starting gun and the moment the first measurable pressure was applied to the toe-boards by each foot, (3) the force exerted by each foot during the entire time the force was applied, and (4) the time over which the force was exerted.

The force required per unit of pen deflection was determined from the calibration of the force-blocks and this provided a multiplier (Y). The subject's impulse was calculated using the formula, $I = AY/P$, (Figure 6).

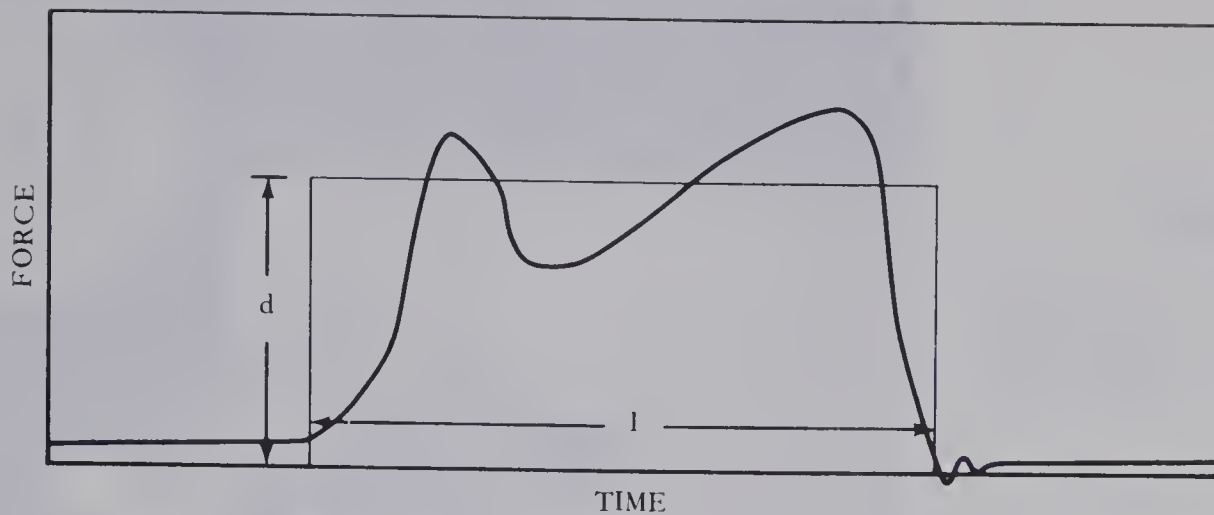


FIGURE 6
A FORCE-TIME GRAPH

$$P = l/t : \bar{F} = \bar{d}/Y$$

$$\therefore l = Pt \text{ and } \bar{d} = \bar{F}/Y$$

$$\text{Since } A = \bar{d}l$$

$$\therefore A = FPt/Y$$

$$\text{Since } I = Ft \text{ (37:62)}$$

$$\therefore A = IP/Y \text{ and } I = AY/P$$

(P) - paper speed

(l) - length of graph

($\bar{d}$) - average height of graph

(t) - time

(F) - force

(A) - area of graph

(I) - impulse

After the impulse of the subject had been calculated, his velocity at the moment his front foot left the toe-board was determined using the formula; $v = I/m$. This formula was determined as follows:

$$Ft = m(v_1 - v_0) \text{ (37:62)}$$

(v_1) final velocity

$$\text{since } v_0 = 0 \text{ and } Ft = I$$

(v_0) initial velocity.

$$\therefore v = I/m$$

Cinematographical analysis. The first step in making the cinematographical analysis was to project the film on a screen then select and label two frames of each start. The first frame (Frame I) selected showed the subject immediately after his front foot had lost contact with the toe-board, (Figure 8) and the second frame (Frame II) pictured the subject the moment prior to his back foot touching

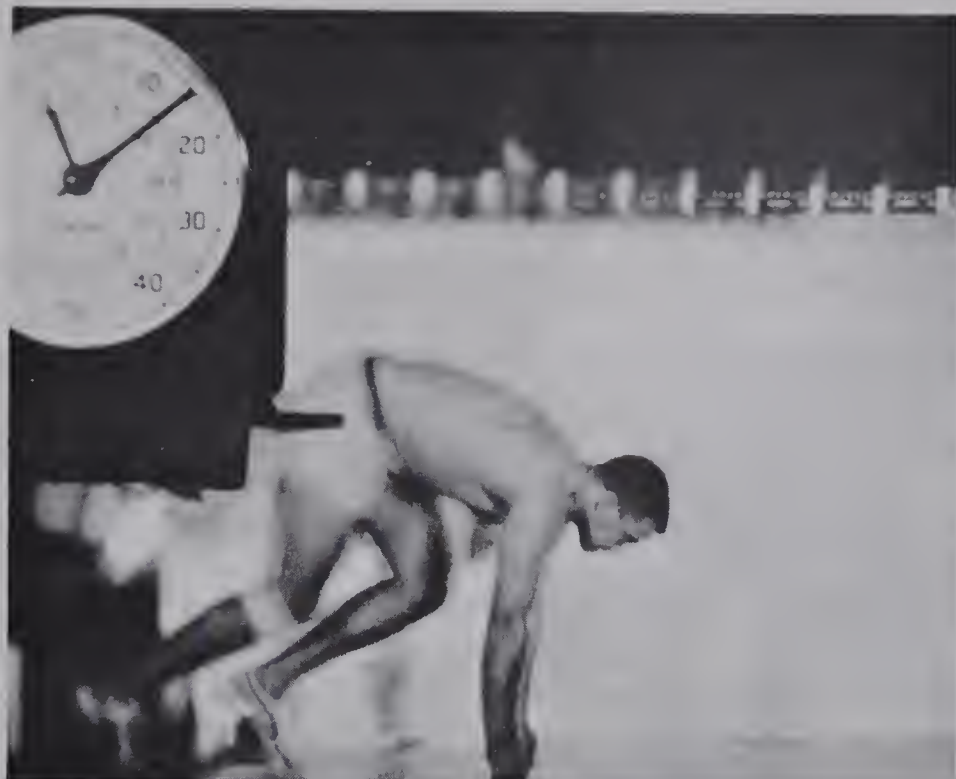


FIGURE 7

SUBJECT IN SET POSITION
THE MOMENT GUN IS FIRED

FIGURE 8

FRAME I, SHOWS SUBJECT
AS FRONT FOOT LEAVES THE
TOE-BOARD

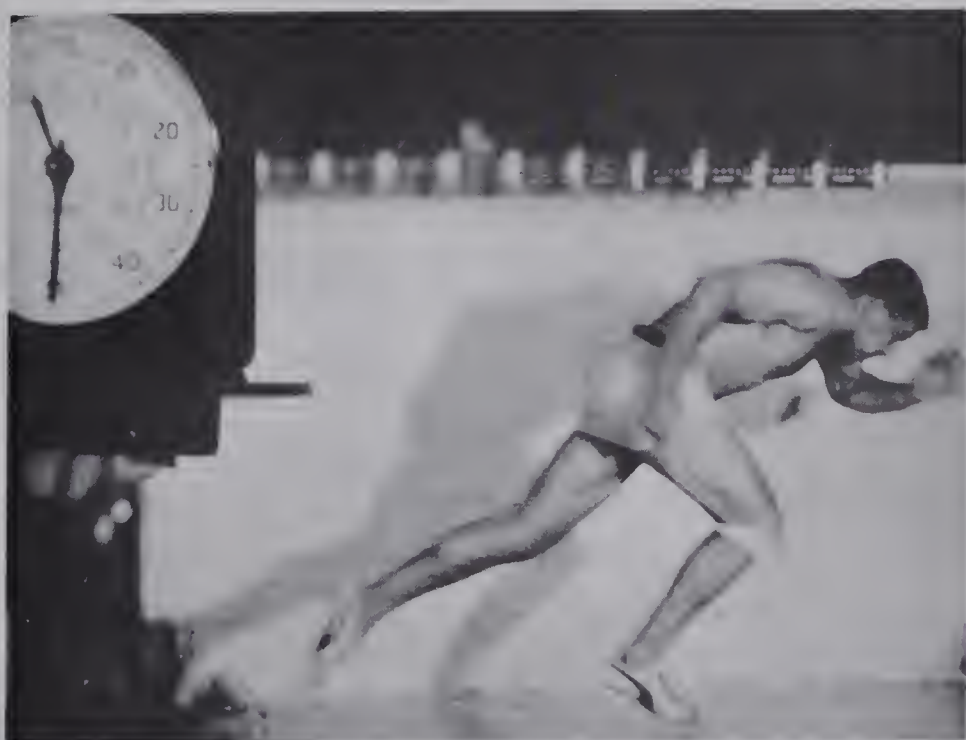


FIGURE 9

FRAME II, SHOWS SUBJECT
BEFORE BACK FOOT TOUCHES
THE FLOOR

the floor (Figure 9). These two frames were from six to nine frames apart. It was assumed that the only force affecting the subject's velocity between these two positions was air resistance and this was considered to be negligible. Therefore the average velocity of the subject between Frame I and Frame II was assumed to be the same as his velocity the moment his front foot left the toe-board.

Two methods of cinematographical analysis were used to calculate the subject's velocity. In the first method, Frame I (Figure 8) was projected vertically from a scaffold onto the center of gravity platform. The image of the "Dexion" beam was superimposed upon its drawing, and checked to make certain it was the same size. The subject was then placed on the board (Figure 3) in the same position as his projected image by two administrators. The three scales were then balanced and the readings recorded. The subject dismounted from the platform and Frame II was projected on the platform, the procedure outline above was repeated.

In order to calculate the subject's velocity, it was necessary to determine the distance (D) his center of gravity moved from Frame I to Frame II (Figure 10). The horizontal ordinates (y_1)(y_2) of the subjects center of gravity in Frame I and Frame II were calculated by using the following formula (35:121) based on the principle of moments:

$$\begin{aligned} Wy_1 &= Wb_1X & (\text{Figure 10}) & Wy_2 = Wb_2X \\ y_1 &= Wb_1X/W & & y_2 = Wb_2X/W \end{aligned}$$

$$\text{Since } D = y_1 - y_2$$

$$\therefore D = (Wb_1 - Wb_2) X/W$$

In order to check the administrator's ability to balance the scales, the scale readings W_a and W_c were used to determine the distance (D). The formula used being: $D = (W_{a_2} + W_{c_2}) - (W_{a_1} + W_{c_1}) \times W$.

The average velocity ($\bar{v}$) of the subject, between the position shown in Frame I and that shown in Frame II, was calculated using the formula $\bar{v} = D/t$ (40:34). The time (t) was determined by subtracting the time read on the chronoscope in Frame I from the time read in Frame II.

In the second method of cinematographical analysis, Frame I was projected horizontally onto a large sheet of paper and the image was then traced. A drawing was made near the top of the paper of the "Dexion" beam. Its image was superimposed on the drawing and checked for size and position. The image of the subject in Frame I was then traced on the paper. Frame II was then focused on the paper sheet, a check was made to insure that the beam's image was in the proper position. The tracings were made with two distinctive colours. This procedure was repeated for all of the starts, using a separate sheet of paper for each start.

The paper sheet was taped onto the platform and the subject assisted in assuming the position indicated by the drawing from Frame I. In this method only the scale at B was used. The scale was balanced and the reading (W_{b_1}) was recorded. The subject was then placed in the position shown in the drawing from Frame II and the reading (W_{b_2}) recorded.

The distance (D) and the average velocity ($\bar{v}$) were calculated using the same formulas as described above.

Statistical treatment. The differences between the mean velocities obtained by the three methods was tested for significance with a one-way analysis of variance model (18:229). Duncan's New Multiple-Range test (48:107) was used to determine where, if any, differences between the treatment means occurred.

The degree of relationship between velocities, calculated using various techniques, time taken to sprint twenty yards and maximum force exerted on the blocks by each foot, were determined by means of a Pearson Product-moment correlation matrix program (18:92). This matrix also provided the test re-test reliability coefficients for determining velocity from the force-blocks and the tracings.

CHAPTER IV

RESULTS AND DISCUSSION

I. RESULTS

The subject performed twenty-two starts, that the starter considered to be satisfactory. But starts one and two were discarded due to technical problems in the camera. Starts six and fourteen were deleted after an examination of the graphs indicated that the subject had started before the signal, producing atypical curves. Only eighteen were analysed.

Force-blocks. The means and standard deviations for the two measures of velocity, the maximum force exerted by each foot, the time of the force exerted against the blocks, and the reaction times obtained from the force-graphs are given in Table I.

Cinematographical Analysis. Two sets of velocity values were obtained from one set of tracings by positioning the subject on each tracing twice. A second set of tracings were made to determine a third value of the velocities.

In the vertical projection method the subject was placed on the platform once for each frame, however two measures of velocity were obtained, one using the scale readings at B and another from the sum of scale readings at A and C.

The subject's average velocity was calculated for the first

0.45 seconds of movement.

TABLE I
DATA OBTAINED FROM THE FORCE-GRAPHS

	MEAN	SD
Velocity in feet per second		
Blocks - 1	10.27	+ 0.19
2	10.35	+ 0.22
Maximum force in pounds		
Front foot - 1st peak	154	+ 13.5
2nd peak	177	+ 10.6
Back foot	220	+ 21.3
Time force was exerted in seconds	0.329	+ 0.016
Reaction time in seconds	0.099	+ 0.045
Impulse in pounds per second		
Back foot	18.14	+ 0.835
Front foot	37.56	+ 1.54

TABLE II
DATA OBTAINED BY CINEMATOGRAFICAL ANALYSIS

	MEAN	SD
Velocity in feet per second		
Tracings - 1	11.66	+ 0.87
2	11.85	+ 1.22
3	10.92	+ 1.06
Vertical projections - 1	10.62	+ 1.90
2	10.73	+ 2.19
Average velocity for 0.45 seconds	8.96	+ 0.22
Sprint time for twenty yards in seconds	3.03	+ 0.006
Film speed in frames per second	125.7	+ 7.38

Means and standard deviations for the velocities, the twenty

yard sprint time, and the camera film speed are reported in Table II.

Correlation coefficients. The relationship between the eight velocities, the twenty yard sprint time, the maximum force and impulse exerted by each foot and the time force was exerted on the blocks was calculated using the Pearson-Product-moment correlation coefficient formula. These twelve variates were treated in two overlapping groups; the results are reported in Table III.

One-way analysis of variance of velocity measures. The first value of velocity calculated by each of the three methods (B-1,T-1, V-1) for the eighteen starts are reported in Table IV. A test of significance for homogeneity of variance showed that the variances were different. However Ferguson (18:240) states that the assumptions of variance underlying the analysis of variance are only roughly satisfied and that moderate departures from homogeneity should not seriously affect the inferences drawn from the data.

Table V summarizes the results of a one-way analysis of variance between the velocities. The F-ratio obtained for the three values was statistically significant at the .01 level of significance.

Duncan's New Multiple Range test indicated that the tracing velocity mean was significantly different from the force-blocks velocity mean ($p = .01$) and the vertical projection velocity mean ($p = .05$). However there was not a significant difference between force-block velocity mean and the vertical projection velocity mean. Table VI summarizes these results.

TABLE III
CORRELATION COEFFICIENTS OBTAINED BETWEEN THE MEANS OF
SELECTED VARIATES OF THE TRACK SPRINT START

	B-2	T-1	T-2	T-3	V-1	V-2	S-T	A-V	B-F	F-F	T-B	B-I	F-I
B-1	.73	.10	.30	-.52	-.05	-.04	.03	-.08	-.07	.52	.10	-.35	.83
B-2		.06	.09	-.55	-.34	-.33	-.40	-.22	-.19	.41	.14	--	--
T-1			.78	.36	.30	.29	.03	.37	-.01	.02	.11	.15	-.04
T-2				--	.37	.34	.00	--	--	--	--	--	--
T-3					--	--	--	.56	.13	-.30	-.01	--	--
V-1						.95	.28	.42	-.03	.08	-.05	-.30	.14
A-V									.02	-.14	-.09	--	--
B-F										-.64	-.59	.44	-.33
F-F											.13	-.73	.77
T-B												.28	-.07
B-I													-.81

B-1	Measure of velocity from the force blocks
B-2	Measure of velocity from the force blocks
T-1	Measure of velocity from the tracings
T-2	Measure of the velocity from the tracings
T-3	Measure of the velocity from the tracings
V-1	Measure of velocity from the vertical projections
V-2	Measure of velocity from the vertical projections
S-T	Time required to sprint 20 yards
A-V	Average velocity for first 0.5 seconds of sprint
B-F	Maximum force exerted by the back foot
F-F	Maximum force exerted by the front foot
T-B	Time that force is exerted on the force-blocks
B-I	Impulse exerted by the back foot
F-I	Impulse exerted by the front foot

* Level of significance $p = .05$ is 0.46

TABLE IV
MEASURES OF VELOCITIES DETERMINED BY THREE METHODS
EXPRESSED IN FEET PER SECOND

TRIAL	BLOCKS	VERT. PROJ.	TRACING
3	10.2	9.7	10.5
4	9.8	13.8	11.0
5	10.5	13.7	12.0
7	10.3	11.4	12.0
8	10.3	12.1	13.6
9	10.4	11.9	10.4
10	10.3	7.7	11.5
11	10.2	12.3	13.2
12	10.2	10.5	11.7
13	10.5	12.5	11.7
14	10.6	8.8	12.0
15	10.4	8.2	10.4
17	10.2	8.0	11.4
18	10.1	9.9	11.4
19	10.4	11.4	12.5
20	10.0	8.9	12.1
21	10.3	9.6	11.2
22	10.2	10.6	11.2
MEAN	10.27	10.62	11.5
SD	± 0.19	± 1.90	± 0.87

TABLE V
ONE-WAY ANALYSIS OF VARIANCE FOR THE
THREE METHODS OF MEASURING VELOCITY

Source of Variation	Sum of Squares	df	Mean Square	F
Between	18.669	2	9.335	6.378*
Within	74.645	51	1.464	
TOTAL	93.315	53		

*Statistically significant ($p = .01$).

TABLE VI
DUNCAN'S NEW MULTIPLE-RANGE TEST APPLIED TO THE
DIFFERENCES BETWEEN K=3 TREATMENT MEANS FOR VELOCITY

MEANS	10.27	10.62	11.66	Least* Signif. R.	Least** Signif.R.
10.27	-	0.35	1.39**	R=0.89	R=1.22
10.62		-	1.04*	R=0.85	R=1.16

* Statistically significant (p = .05)

** Statistically significant (p = .01)

Uncertainty of velocity values. In order to estimate the uncertainty or error involved in measuring velocity by the three methods, the following principles as stated by Michels and Patterson (32:607) were used:

1. "When two or more quantities are added or subtracted, the absolute uncertainty in the result is the sum of the absolute uncertainty in the quantities."
2. "When two or more quantities are multiplied or divided, the fractional uncertainty in the result is the sum of the fractional uncertainties in the quantities."

The fractional or relative error (Appendix C) for the velocity value obtained from measurements of the force-graph was 5.4 per cent. This meant that the value of 10.3 feet per second may have had an error of ± 0.6 feet per second.

The relative error of calculating the velocity by the cinematographical methods was determined to be 6.4 per cent. However this did not take into account the possible error involved in positioning the

subject on the center of gravity platform. The mean velocities obtained from two treatments of the tracing method (T-1, T-3), a test re-test procedure, differed by 7 per cent. Assuming that this difference was not unusual, it indicated that subsequent measurements of velocity by the tracing method would vary 3.5 per cent from the mean, as a result of the error in making the tracing and positioning the subject. Combining these errors we obtained a relative error of 10 per cent, which indicated that the value of 11.7 feet per second may have had an error of ± 1.2 feet per second.

II. DISCUSSION

Force-blocks. In measuring the velocity and force of a track sprint start, spring scales, chronoscopes and force-blocks have been the main tools by which physical educators have studied the sprint start. The force-blocks combined with a graph recorder produces a graphical illustration of the force exerted and the time spent on the force-blocks (Figure 11). Howell (26) found that the use of the force-graphs and a knowledge of their results, significantly improved an athletes performance.

From the composite graph of the eighteen starts (Figure 11) it can be seen that both feet begin to exert pressure at very nearly the same time. The front foot applies force more slowly but reaches an initial peak of 154 pounds at the same time that the back foot exerts its maximum force of 220 pounds. The force exerted by the front foot decreases approximately forty pounds before exerting its maximum force of 177 pounds against the toe-board, which was 45 per

cent of this being contributed by the front foot. The combined maximum force exerted by Kistler's (28) subjects was 346 pounds; this magnitude being similar to that obtained in this study, however, the relative contribution from each foot was reversed as 56 per cent was contributed by the front foot, in Kistler's study.

In an examination of the impulse exerted by each foot the importance of the front foot to velocity becomes more apparent. This foot contributes 67 per cent of the total impulse and hence of the velocity obtained in the sprint start. The results that Henry (24) obtained for the six fastest sprinters, concerning the relative contribution by each foot to the total impulse were of the same ratio.

The time that force was exerted on the blocks was very similar to results obtained by Henry (24) being 0.32 seconds and 0.345 respectively.

The estimated error in measuring velocity from the force-blocks was 5.4 per cent. Therefore each of the two means, 10.3 and 10.4 feet per second, had a measurement error of ± 0.6 feet per second.

Henry (24) calculated the velocity for the bunch starts to be 6.6 feet per second. The medium start produced the greatest velocity which was 7.5 feet per second. He did not report his estimated error of measurement, however he did report that the error of measuring the time that force was exerted against the blocks to be 12 per cent. His mechanical arrangement of rods, pinions, roller bearings and universal joints converted the horizontal movement of the blocks to rotary movement and back to horizontal movement of a pen that recorded

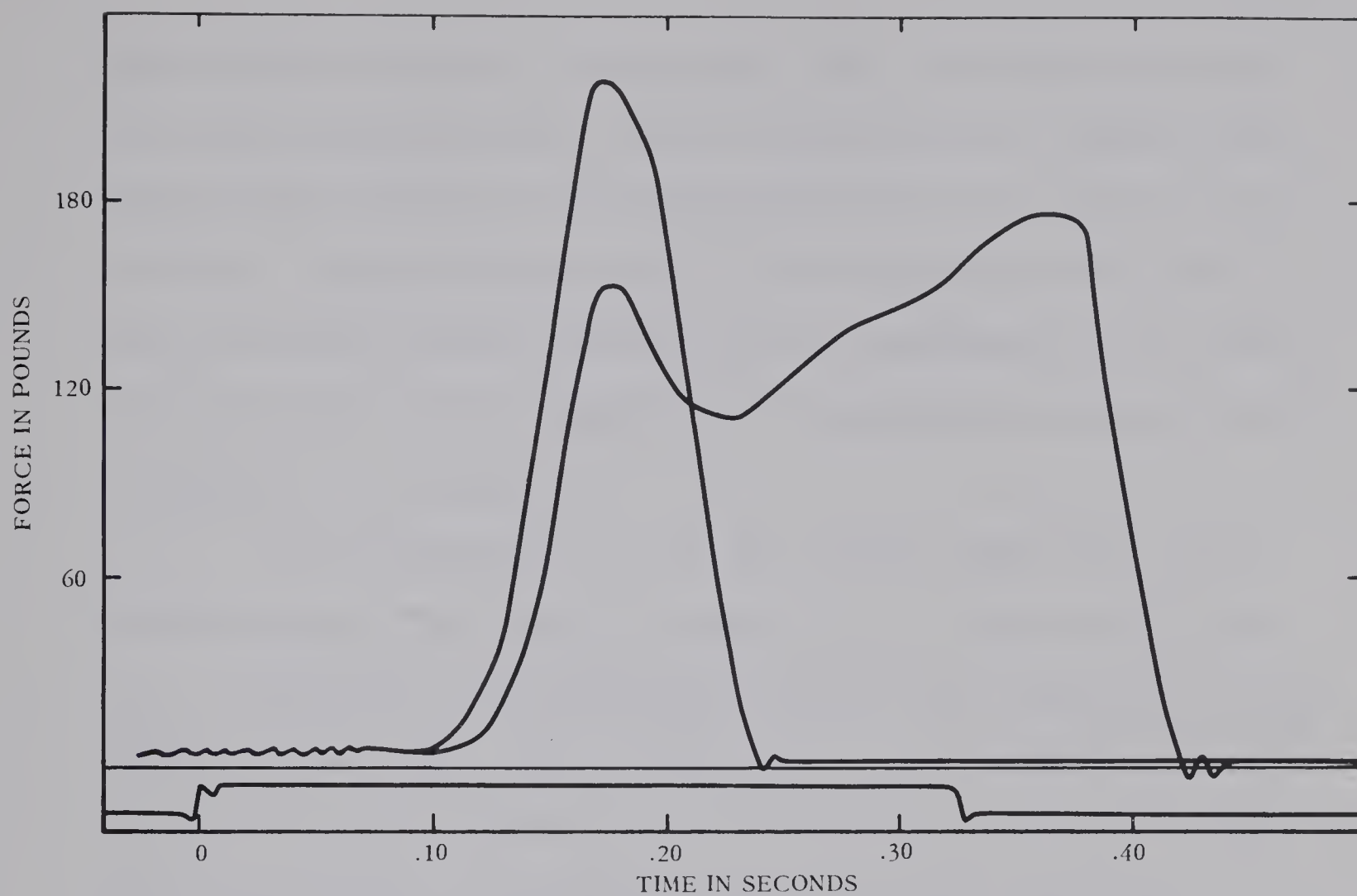


FIGURE 11
COMPOSITE FORCE TIME GRAPH OF 18 STARTS

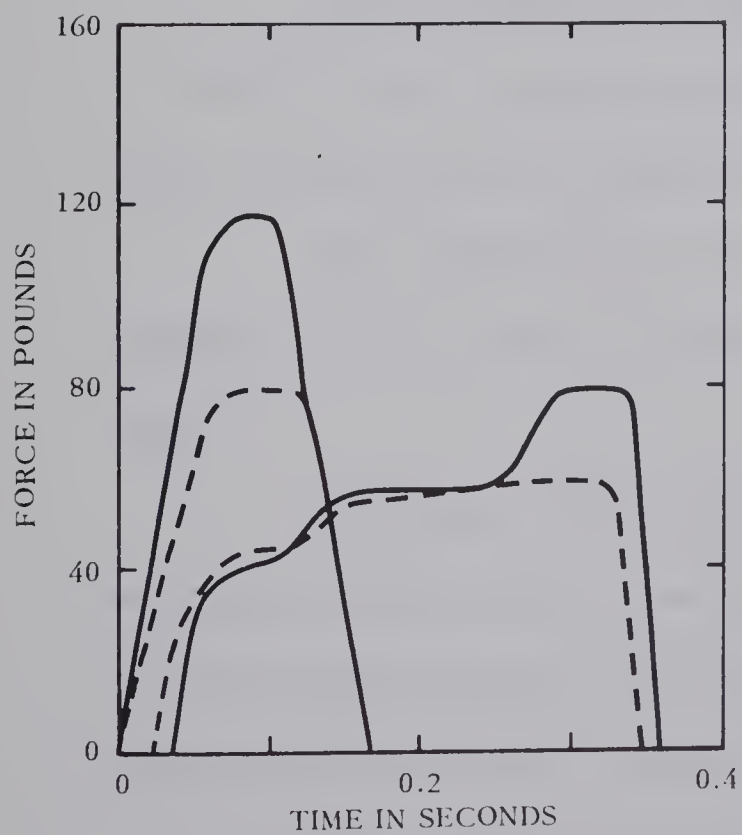


FIGURE 12
SLOW STARTS FROM HENRY

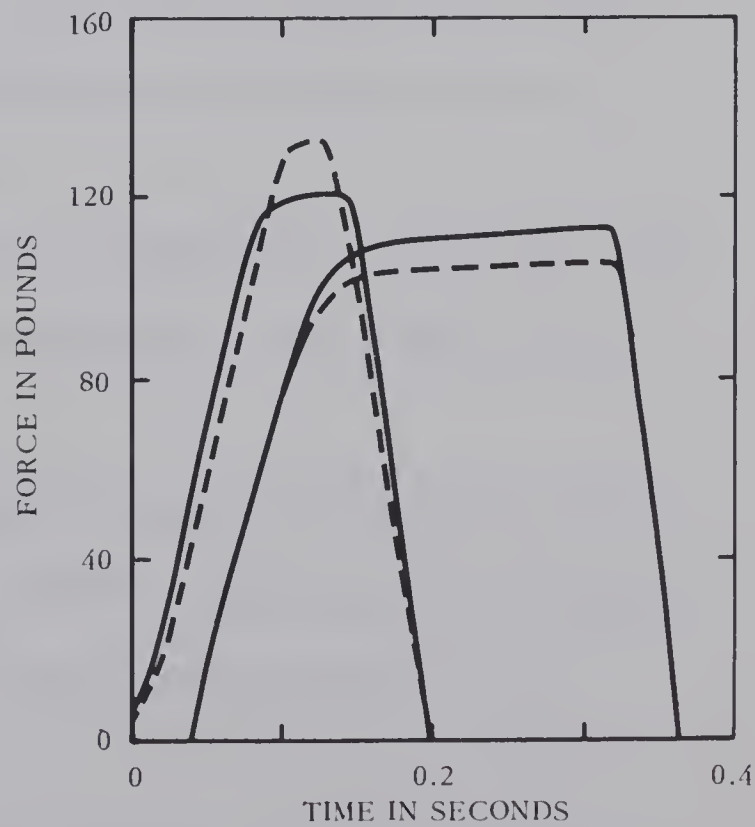


FIGURE 13
FAST STARTS FROM HENRY

the original movement on a chronograph. Also, the blocks moved $\frac{3}{8}$ of an inch horizontally when a force of 160 pounds was applied, this was six times as great as the movement observed in the blocks used in the study. It may have been that the low velocities and the small forces reported by Henry (24) were due to a combination of the above measurement error and the dissipation of information by the mechanical arrangement of the apparatus.

It is interesting to note that Russell (36) using a force platform measured velocities of sixteen feet per second in the swim start. However the swimmer may have received added assistance from the symmetrical arm swing. Also the fact that he did not have to exert considerable force to bring the body to an upright position, as did the track sprinter, may explain in part the greater velocities.

Cinematographical analysis. The small variance in the time of 3.03 (± 0.006) seconds to sprint twenty yards indicated that the starts contributed to similar sprints.

The calculation of time used in determining velocity by these methods, was the source of greatest measurement error, being four per cent.

The mean velocities determined by cinematographical methods were greater than those from the force-blocks. This provides evidence that the force-blocks, used in this study, did not yield an over estimation of starting velocity.

The average velocity was nine feet per second for the first 0.45 seconds of movement. The subject's center of gravity moved 4.1 feet in this period. Henry (24:310) presented a graph illustrating

the influence of the four starting positions on the velocity for the first few yards of the sprint run. The graph indicated that the bunch start enabled the sprinter to achieve an average velocity of 4.0 feet per second for the first 0.45 seconds of movement. The elongated start resulted in the greatest average velocity of 5.3 feet per second. The sprinters' center of gravity travelled 1.8 feet and 2.4 feet respectively. Possible explanations for these relatively small velocity values has been stated above.

Correlation coefficients. The high correlation of 0.95 between the two measures of velocity by the vertical projection method is a measure of the reliability in determining the subject's center of gravity using two sets of scales.

The reliability coefficient of 0.73 between the values calculated from two sets of measurements of the force-graphs indicates the degree of reliability in measuring these areas. However the large number of similar velocity values (Appendix A) obtained by this method prevented this coefficient from being higher. The similarity of scores reflected the fact that a trained athlete was used as the subject.

The first two sets of values obtained by the tracing method resulted in a reliability coefficient of 0.78, which is an indication of the ability of the administrator to position the subject on the platform in the same position. The very low correlation (0.36) between the values from the first and third sets tracings may be explained in part by the large relative error (10 per cent) in determining velocity

by this method.

We would have expected a higher negative correlation between velocity values and the time to sprint twenty yards, but results did not bear out this expectation. One possible explanation is that the effect of the starting velocity is lost over this distance. A second explanation might be in the fact that there were numerous tied scores in both velocity and time taken to sprint twenty yards. Also a higher positive correlation was expected between average velocity and velocity on leaving the blocks. The velocity values were rounded-off to the nearest tenth, resulting in a large number of tied scores. This fact combined with the large error involved in making measurements of velocity from the film could have been contributing factors in obtaining a low correlation coefficient.

Low correlations according to Ferguson (18) do not necessarily invalidate a test. That only one subject was used and a relatively small number of starts were studied is, in part, responsible for some of the low correlations.

The high correlation of 0.83 of the front foot impulse and the low negative correlation of -0.35 of the back foot impulse to the velocity measured on the force-blocks points out the great importance of the front foot's contribution to achieving a high velocity on leaving the force-blocks. This relationship is further supported by the high negative correlation of -0.81 between front foot and back foot impulse. These findings support those of Henry's (24:308). This implies that the start which enables the sprinter to achieve the greatest impulse from the front foot and the smallest impulse from the back foot will

result in the greatest starting velocity. The forward thrust of the back leg early in the starting sequence must enable this subject to make the best use of the resulting, equal and opposite reaction on the front toe-board. The limits of the above implications need to be more fully examined.

There was no significant correlation coefficient between time spent thrusting against the start-blocks and the impulse of the front foot.

One-way analysis of variance. The method of calculating velocity by the tracing method resulted in significantly higher velocities than those obtained by the other two methods. Compared to the results reported by Henry (24) the tracing method showed a greater discrepancy than did force-blocks and vertical projection in measuring velocity.

Since the tracing method required that more measurements be made in calculating velocities, it follows that there were more sources of error which may account in part for the higher values obtained.

The results obtained by the force-block and the vertical projection method did not differ significantly, and it would therefore seem that the resulting values were a close approximation of the true velocity for these sprint starts.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The purpose of this study was to compare the use of force-blocks and cinematography in the measurement of horizontal velocity obtained in the track sprint start.

A member of the University of Alberta track team, who was considered to be one of the best sprinters on the team over a distance of fifty yards, was used as the subject. The toe-boards were spaced twelve inches apart, which was the subject's preferred spacing. Eighteen sprint starts were analysed.

Force-blocks, used in this study, measured the horizontal force by means of a displacement transducer, which generated a potential difference proportional to the force. The potential difference was recorded on graph paper by pen deflection on a paper. By calculating the subject's mass and measuring the area under the force-time graph, his velocity, the moment he lost contact with the toe-board, was calculated.

Each start was recorded on film by a camera having a film speed setting of 128 frames per second. Two film frames of each start were selected, which recorded the subject's body position the moment his front foot left the toe-board and the moment before his back foot touched the floor. The horizontal movement of the subject's mass

center of gravity was determined by measuring the change in the distribution of his weight on a platform, when the subject was placed in the positions recorded on each of the two selected frames. A tracing of the subject's image in each position, was placed on the platform to provide a guide in positioning the subject for weighing. A second method was also used in which the subject's image from each of the two frames was projected vertically on the platform.

The velocity of the subject, the moment he lost contact with the toe-board, was calculated using the horizontal distance travelled by his mass center of gravity and the elapsed time, between the two frames, recorded on the film.

II. CONCLUSIONS

On the basis of the results obtained the following conclusions appear to be justified.

1. There is not significant difference between the mean velocities as measured by the force-block and the vertical projection methods.
2. The mean velocities measured by the force-block and the tracing method are significantly different.
3. In this study the relative error in determining velocity by cinematographical analysis is twice as large as by the force-block method.
4. The force-blocks provide a quick method of determining velocity and impulse compared to cinematographical analysis.
5. It is not likely that the true mean velocity of the

eighteen starts is less than $10.3 (+0.6)$ feet per second, since the mean velocities obtained by the other two methods are greater.

6. Despite the fact that the back foot exerts a greater maximum force in the start, the front foot contributes twice the impulse to the final block velocity as does the back foot.

III. RECOMMENDATIONS

The following recommendations are a result of problems encountered and insights gained during the course of this study.

1. A study should be conducted to determine the point on the force-time graph that the foot loses contact with the toe-board.

2. The displacement transducer on the force-blocks should be replaced by piezoelectric accelerometers which have a greater range of linearity and greater sensitivity.

3. Provision should be made to measure time to the nearest thousandth of a second when calculating velocity in the track sprint start, using cinematography.

4. The objectivity and reliability should be determined for positioning a subject in a desired sprinting position on a center of gravity platform.

5. A study should be conducted using the force-blocks, to compare the resulting velocities and sprint times from different types of track sprint starts.

6. A study should be done to examine the relative importance to velocity, of force and impulse exerted by each foot.

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APPENDIX A

RAW SCORES

DATA FROM MEASUREMENTS OF VELOCITY AND IMPULSE

TRIAL	VELOCITY (ft/sec)								IMPULSE (lbs/sec)	
	B-1	B-2	T-1	T-2	T-3	V-1	V-2	A-V	B-I	F-I
3	10.2	10.3	10.5	9.8	11.2	9.7	9.8	8.7	18.3	37.3
4	9.8	9.8	11.0	11.5	12.9	13.8	14.2	9.2	19.7	33.6
5	10.5	10.4	12.0	13.0	12.1	13.7	16.1	9.1	17.4	39.4
7	10.3	10.3	12.0	11.8	9.9	11.4	11.7	9.1	18.2	37.7
8	10.3	10.3	13.6	13.0	11.9	12.1	12.4	9.3	18.2	37.6
9	10.4	10.5	10.4	10.2	10.0	11.9	11.9	9.0	16.6	39.8
10	10.3	10.4	11.5	10.8	9.5	7.7	7.7	9.2	19.6	36.4
11	10.2	10.2	13.2	12.7	12.8	12.3	12.3	8.8	18.0	37.2
12	10.2	10.4	11.7	11.6	11.7	10.5	10.5	8.7	18.3	37.2
13	10.5	10.5	11.7	12.8	10.8	12.5	11.0	8.8	18.0	38.9
14	10.6	10.5	12.0	13.5	10.1	8.8	8.7	8.8	19.4	38.1
15	10.4	10.5	10.4	10.6	9.6	8.2	8.2	8.7	18.0	38.3
17	10.2	10.8	11.4	11.3	10.9	8.0	8.1	8.7	18.5	36.7
18	10.1	10.2	11.4	11.5	10.9	9.9	9.9	9.0	17.7	37.1
19	10.4	10.6	12.5	14.4	9.5	11.5	11.6	9.4	17.7	39.1
20	10.0	10.0	12.1	12.3	11.5	8.9	8.9	8.9	19.7	34.6
21	10.3	10.3	11.2	10.7	9.6	9.6	9.9	8.8	17.5	38.2
22	10.2	10.3	11.2	11.8	10.6	10.6	10.3	9.1	16.7	38.9
$\bar{x}$	10.27	10.35	11.66	11.85	10.92	10.62	10.73	8.96	18.14	37.56
S	0.190	0.223	0.872	1.218	1.060	1.896	2.193	0.219	0.835	1.541

- B-1 First measure of velocity from the force blocks
- B-2 Second measure of velocity from the force blocks
- T-1 First measure of velocity from the tracings
- T-2 Second measure of velocity from the tracings
- T-3 Third measure of velocity from the tracings
- V-1 First measure of velocity from the vertical projections
- V-2 Second measure of velocity from the vertical projections
- A-V Average velocity for the first 0.45 seconds of movement
- B-I Impulse exerted by the back foot
- F-I Impulse exerted by the front foot

DATA FROM MEASUREMENTS OF TIME AND FORCE

TRIAL	TIME (SEC)			FORCE (lbs)			FILM SPEED	TIME IN THE AIR			
								TRACING		VERTICAL	
	T-B	R-T	S-T	B-F	FF-1	FF-2	f/s	F	T	F	T
3	0.308	0.12	3.05	241	171	176	140	8	0.060	8	0.060
4	0.332	0.06	3.06	238	133	151	139	6	0.040	6	0.040
5	0.320	0.11	3.01	227	166	190	137	7	0.050	6	0.040
7	0.328	0.10	3.04	217	155	183	127	8	0.062	7	0.054
8	0.324	0.11	3.04	223	168	166	124	8	0.065	7	0.056
9	0.328	0.14	3.04	217	166	181	132	9	0.070	7	0.050
10	0.328	0.11	3.06	235	155	168	117	6	0.060	4	0.038
11	0.324	0.11	3.05	217	141	181	135	7	0.050	6	0.042
12	0.376	0.00	3.20	160	121	193	125	8	0.062	7	0.052
13	0.328	0.11	3.08	241	155	178	125	7	0.058	6	0.044
14	0.344	0.11	3.04	239	148	173	120	6	0.048	5	0.042
15	0.344	0.06	3.04	197	161	176	121	9	0.074	7	0.056
17	0.320	0.14	2.76	236	163	175	121	8	0.066	7	0.056
18	0.320	0.12	3.02	223	158	178	119	8	0.066	7	0.058
19	0.344	-0.03	3.02	197	141	190	117	6	0.050	4	0.032
20	0.332	0.13	3.02	241	145	163	121	6	0.048	4	0.034
21	0.308	0.16	3.06	217	173	185	121	7	0.058	6	0.048
22	0.312	0.12	3.03	199	155	187	121	9	0.074	7	0.056
x	0.329	0.099	3.03	220	154	177	125.7		0.059		0.048
S	0.0160	0.045	0.079	21.3	13.5	10.6	7.38		0.010		0.010

T-B Time that force is exerted on the blocks

R-T Reaction time

S-T Time required to sprint twenty-yards

B-F Maximum force exerted by the back foot

FF-1 First peak of the maximum force exerted by the front foot

FF-2 Second peak of the maximum force exerted by the front foot

f/s Frames per second

F No. of frames from Frame I to Frame II

T Elapsed time from Frame I to Frame II

DATA FROM MEASUREMENTS OF THE FORCE-GRAPHS

TRIAL	Mean of 5 Readings of Each Graph (sq. in.)			
	Back Foot		Front Foot	
	B-1	B-2	B-1	B-2
3	0.588	0.586	1.073	1.090
4	0.634	0.640	0.968	0.966
5	0.560	0.548	1.134	1.140
7	0.586	0.594	1.056	1.084
8	0.586	0.578	1.082	1.088
9	0.534	0.546	1.144	1.158
10	0.630	0.636	1.046	1.048
11	0.578	0.570	1.070	1.088
12	0.590	0.588	1.070	1.094
13	0.580	0.586	1.118	1.124
14	0.624	0.606	1.096	1.104
15	0.578	0.578	1.102	1.118
17	0.596	0.602	1.056	1.068
18	0.570	0.560	1.068	1.086
19	0.570	0.578	1.124	1.144
20	0.634	0.638	0.996	1.002
21	0.562	0.562	1.100	1.100
22	0.536	0.548	1.118	1.124

APPENDIX B
CALIBRATIONS

CALIBRATION OF THE FORCE-BLOCKS

TRIALS	Pounds Force Applied To:									
	Pen Deflection (mm) of Left Block					Pen deflection (mm) of Right Block				
	50	99.5	149	200	249.25	50	99.5	149	200	249.25
1	6.0	14.5	22.2	30.0	37.5	7.8	16.2	05.0	33.2	40.2
	6.0	14.8	22.5	30.0	37.5	7.8	16.2	25.0	33.2	40.2
	6.0	14.5	22.8	30.0	37.5	7.8	16.2	25.0	33.2	40.2
2	6.5	14.5	22.2	30.5	37.5	8.0	16.5	25.0	33.5	40.5
	6.5	15.0	22.5	30.5	38.0	8.0	16.5	25.0	33.5	40.5
	60.0	14.5	22.8	30.5	38.0	8.0	16.5	25.0	33.5	40.5
3	6.0	14.2	22.5	30.0	37.5	8.2	16.5	25.0	33.5	41.5
	6.0	14.2	22.8	30.2	37.5	8.0	16.5	25.0	33.5	41.5
	6.0	14.8	22.8	30.2	37.5	8.0	16.5	25.0	33.5	41.2
4	6.0	14.2	22.5	30.2	37.0	8.0	16.5	25.0	33.5	41.0
	6.0	14.5	22.8	30.0	37.0	8.0	16.5	25.0	33.5	41.0
	6.0	15.0	23.0	30.0	37.5	8.0	16.5	25.0	33.5	40.8
5	6.5	14.5	22.5	30.5	38.0	8.0	16.5	25.0	33.5	41.0
	6.5	14.5	22.8	30.5	37.5	8.0	16.5	25.0	33.5	41.0
	6.5	15.0	22.5	30.0	38.0	8.0	16.5	25.0	33.5	41.0
6	6.5	14.2	22.5	31.0	38.0	8.0	16.5	25.2	33.5	41.0
	6.5	14.5	23.0	30.5	37.8	8.0	16.5	25.2	33.5	41.0
	6.5	14.5	23.8	30.5	37.8	8.0	16.8	25.2	33.5	41.0
7	6.0	14.0	23.2	29.0	36.0	8.0	16.5	25.0	33.5	40.2
	6.0	14.0	23.8	29.0	36.5	8.0	16.5	25.0	33.5	40.2
	6.0	14.5	23.2	29.0	37.0	8.0	16.5	25.0	33.5	40.2
8	6.0	14.0	23.2	29.0	36.0	7.8	16.5	25.0	33.2	40.5
	6.0	14.5	21.8	29.5	36.0	8.0	16.2	25.0	33.2	40.5
	6.0	14.2	22.2	30.0	36.2	8.0	16.2	25.0	33.2	40.5
9	6.0	14.0	22.8	30.0	37.0	8.0	16.8	25.0	33.8	40.8
	6.0	14.8	22.2	30.0	37.0	8.0	16.8	25.0	33.5	40.8
	6.0	14.5	22.5	30.0	37.0	8.0	16.8	25.0	33.5	40.8
10	6.0	14.5	22.2	29.2	36.5	8.0	16.5	25.0	33.8	40.8
	6.5	14.5	21.8	39.8	36.5	8.0	16.5	25.2	33.8	40.8
	6.5	14.8	22.0	29.8	36.5	8.0	16.5	25.5	33.8	41.0
$\bar{X}$	6.17	14.47	22.48	29.98	37.18	7.98	16.59	25.04	33.48	40.74
$\bar{y}^*$	8.10	6.88	6.63	6.67	6.70	6.27	6.03	5.95	5.97	6.12

*Mean Pen Deflection Expressed in Pounds per Millimeter

DETERMINATION OF A MEAN PEN DEFLECTION FOR EACH FORCE-BLOCK

The resulting pen deflection when a fifty pound force was applied to the force-blocks, did not appear to conform to a linear pattern compared to the results obtained by applying the other four selected forces. This was particularly evident in the case of the left force-block. These observations were confirmed by plotting the amounts of pen deflection on a graph.

A probable explanation for this behavior was that the core of the transducer was not accurately positioned. This was difficult to do as the limits of the transducers linear performance were narrow relative to the range of forces being applied.

The lower portion of a force-graph was replotted using the mean pen deflection value obtained by applying a force of fifty pounds, compared to a mean of the other four values. Since in this portion of the graph the curve was close to the vertical, the observed differences in the resulting areas was very slight, and less than the measurement error. Therefore, the amount of pen deflection was considered to be the mean of the values obtained when forces of 99.5, 149, 200 and 249.25 pounds were applied to the force-blocks.

Each of the 120 values obtained for each force-block, reported in the table above, was converted to pounds force required to deflect the pen one millimeter. A mean and standard deviation, expressed in pounds per millimeter, was obtained for each force-block as follows:

Left Block: $\bar{X} = 6.72$

$S = 0.152$

Right Block: $\bar{X} = 6.02$

$S = 0.084$

CALIBRATION OF THE BRUSH RECORDER

Distance*	Time **	Speed***	Distance	Time	Speed
36.0	0.29	124.1	89.5	0.72	124.3
49.0	0.39	125.6	72.0	0.58	124.1
38.5	0.31	124.2	83.0	0.66	125.8
41.5	0.33	125.8	86.0	0.69	124.6
62.0	0.49	126.5	87.5	0.70	125.0
51.0	0.41	124.4	70.5	0.56	125.9
39.0	0.31	125.8	76.0	0.61	124.6
61.0	0.49	124.5	62.5	0.50	125.0
40.5	0.32	126.6	65.5	0.52	126.0
47.0	0.38	123.7	71.0	0.57	124.6
110.5	0.88	125.6	154.5	1.24	124.6
117.5	0.94	125.0	126.0	1.01	124.8
102.0	0.82	124.4	127.0	1.02	124.5
115.5	0.93	124.2	135.0	1.07	126.2
104.0	0.83	125.3	149.0	1.19	125.2
116.0	0.93	124.7	148.0	1.18	125.4
100.5	0.81	124.1	142.5	1.14	125.0
115.0	0.92	125.0	137.5	1.10	125.0
115.0	0.92	125.0	143.5	1.15	124.8
97.5	0.79	123.4	149.5	1.20	124.6
164.0	1.31	125.2	173.0	1.39	124.5
178.0	1.43	124.5	182.0	1.45	125.5
181.0	1.45	124.8	175.5	1.41	124.5
163.5	1.31	124.8	157.5	1.27	124.0
166.5	1.33	125.2	161.0	1.29	124.8
N = 50	$\bar{X} = 124.9$	S = 0.68			

* Distance the graph paper travelled in millimeters

** Time the graph paper travelled in seconds

*** Speed of the graph paper in millimeters per second

CALIBRATIONS OF THE PLANIMETER

Planimeter (sq. in.)		Force-graph of Back Foot		Force-graph of Front Foot	
B-1	B-2	B-1	B-2	B-1	B-2
39.97	40.00	0.59	0.62	1.09	1.09
39.98	39.99	0.56	0.59	1.07	1.10
40.00	39.99	0.59	0.58	1.05	1.10
40.01	39.98	0.58	0.58	1.08	1.10
40.00	39.99	0.58	0.58	1.09	1.10
39.97	39.98	0.61	0.58	1.09	1.08
39.99	39.99	0.58	0.58	1.06	1.09
40.00	40.00	0.59	0.58	1.07	1.06
40.02	39.99	0.59	0.59	1.07	1.10
39.99	39.99	0.61	0.58	1.06	1.08
$\bar{X}=39.99$	39.99	0.588	0.586	1.073	1.09
$S=0.0141$	0.010	0.0141	0.0141	0.0148	0.010

APPENDIX C

CALCULATION OF ERROR

DETERMINATION OF THE ACCUMULATED ERRORS

The following principles as stated by Michels and Patterson (32:607) were used to determine the accumulated error in calculating impulse and velocity:

1. "When two or more quantities are added or subtracted the absolute uncertainty in the result is the sum of the absolute uncertainty in the quantities."
2. "When two or more quantities are multiplied or divided, the fractional uncertainty in the result is the sum of the fractional uncertainties in the quantities."

Force-blocks. To determine the relative error in measuring the impulse, using the formula $I = A_1 Y_1 + A_2 Y_2 / P$, exerted on the force-blocks the following formula was developed based on the above principles:

$$\frac{i}{I} = \frac{a_1 Y_1 + y_1 A_1 + a_2 Y_2 + y_2 A_2}{A_1 Y_1 + A_2 Y_2} + \frac{p}{P}$$

in which:

A_1 is the area under the force-graph of the back foot

A_2 is the area under the force-graph of the front foot

Y_1 is the amount of pen deflection for the right block

Y_2 is the amount of pen deflection for the left block

P is the speed of the graph paper

I is the impulse exerted on the force-blocks

The lower case of each symbol represents the absolute error of its value.

By substitution we have:

$$\frac{i}{I} = \frac{(0.014)(153) + (2.13)(0.588) + (0.015)(171) + (3.86)(1.073)}{(0.588)(153) + (1.073)(171)} + \frac{0.027}{4.92}$$

$$\frac{i}{I} = 0.042 \text{ or } 4.2\%$$

To determine the relative error in measuring the velocity, using the formula $v = I/m$, of the subject the moment he leaves the force-blocks the following formula was developed:

$$\frac{\Delta v}{v} = \frac{i}{I} + \frac{\Delta m}{m}$$

in which:

v is the calculated velocity of the subject

Δv is the absolute error of the velocity value

m is the measure of the subjects weight

Δm is the absolute error in measuring the subjects weight

By substitution we have:

$$\frac{\Delta v}{v} = 0.042 + \frac{2}{174}$$

$$\frac{\Delta v}{v} = 0.054 \text{ or } 5.4\%$$

Cinematography. To determine the relative error in measuring the velocity, using the formula $v = D/t = \frac{(W_1 - W_2) X}{W \cdot t}$, of the subject the moment he left the force-blocks the following formula was developed:

$$\frac{\Delta v}{v} = \frac{(w_1 + w_2)}{(W_1 - W_2)} + \frac{x}{X} + \frac{w}{W} + \frac{t}{T}$$

in which: (See Figure 10)

W_1 is the scale reading with the subject in the Frame I position

W_2 is the scale reading with the subject in the Frame II position

X is the perpendicular distance from B to the line AC

W is the weight of the subject

T is the elapsed time between Frame I and Frame II

The lower case of each symbol represents the absolute error of

its value.

By substitution we have:

$$\frac{\Delta v}{v} = \frac{(0.13 + 0.13)}{100 - 75} + \frac{0.13}{69.9} + \frac{2}{174} + \frac{0.002}{0.05}$$

$$\frac{\Delta v}{v} = 0.064 \text{ or } 6.4\%$$

The relative error in positioning the subject was estimated to be 3.5 per cent, based on test re-test information. Therefore, the total relative error in measuring the subject's velocity was approximately 10 per cent.

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